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Supporting Information for "Value of long-term streamflow forecast to reservoir operations for water supply in snow-dominated catchments"

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Introduction The present supporting information contains full details of the reservoir model and the Model Predictive Control formulation.

Text S1. MPC control problem formulation

The control problem formulation used in the forecast-based adaptive framework is as follows

$$\min_{m_t} J_{irr} = \sum_{t=\bar{t}}^{\bar{t}+h-1} \Big[\max(w_t - r_t, 0) \Big]^2 + G(s_{\bar{t}+h}) \tag{1a}$$

$$\text{subject to} \tag{1b}$$

$$u_t = m_t(s_t) \qquad \forall t = [\bar{t}, \bar{t}+1, \cdots, \bar{t}+h-1] \tag{1c}$$

$$s_{t+1} = s_t + q_{t+1} - r_{t+1} - E(s_t, t) \qquad \forall t = [\bar{t}, \bar{t}+1, \cdots, \bar{t}+h-1] \tag{1d}$$

$$\underline{s} \leq s_t \leq \bar{s}_t \qquad \forall t = [\bar{t}, \bar{t}+1, \cdots, \bar{t}+h-1] \tag{1e}$$

$$r_{t+1} = R_t(u_t, s_t, q_{t+1}) \qquad \forall t = [\bar{t}, \bar{t}+1, \cdots, \bar{t}+h-1] \tag{1f}$$

$$w_t \quad \text{given} \qquad \forall t = [\bar{t}, \bar{t}+1, \cdots, \bar{t}+h-1] \tag{1g}$$

$$q_{t+1} \quad \text{given} \qquad \forall t = [\bar{t}, \bar{t}+1, \cdots, \bar{t}+h-1] \tag{1h}$$

$$G(s_{\bar{t}+h}) \quad \text{given} \tag{1i}$$

The decision variable u_t represents the volume to be released from the reservoir at time t. The decision is defined by the control policy $m_t(\cdot)$. r_{t+1} represents the volume actually released from the reservoir between time t and $t+1$. u_t and r_{t+1} differ just when the reservoir spills. $R_t(\cdot)$ represents the release function which transform the release decision into actual release from the reservoir. It accounts for the spillways level-release function of the reservoir. s_t represents the reservoir storage at time t and is computed through a mass balance equation which accounts for the reservoir inflows q_{t+1}, representing the volume flowing into the reservoir between time t and $t+1$, the actual reservoir release r_{t+1}, and the evaporation loss $E(s_t, t)$ between time t and $t+1$. The evaporation loss is modeled as a function of reservoir storage and time of the year. The function is calibrated based on historical records, i.e., observed time series of storage and evaporation on the period 01.01.2000 - 31.12.2012. Figure 1 shows the function resulting from the fitting of the historical records. The coefficient of determination of the evaporation model is 0.68. The evaporation model is then used within the mass balance model to simulate the reservoir storage. Figure 2 shows the scatter plot of observed and simulated storage. The model can correctly represent the observed storage time series, with a coefficient of determination of 0.98 and a daily mean relative bias confined within -0.5% and 2%. w_t is the water demand as described in the paper (see Section 2). The flood control storage is represented by the upper bound on the storage $\bar{s}_t$ as shown by the lower curve in Figure 2b of the paper. $G(\cdot)$ represents the penalty on the reservoir storage at the end of the horizon. This is arbitrarily fixed to a constant function. Note that we are using a rolling over horizon, so the effect of the penalty on the release decision at time t is marginal.

We solved the MPC using Deterministic Dynamic Programming (DP). As required by DP, we discretized the state variable, i.e., the reservoir storage s_t, using 133 grid points, the disturbance, i.e., the reservoir inflow q_{t+1}, using 55 grid points, and the decision variable, i.e., the reservoir release volume u_t, using a time dependent discretization ranging from 23 to 84 points. In this case, the number of grid points is variable to better adjust to the pattern and range of variation of the water supply demand (see Figure 2b in the paper).

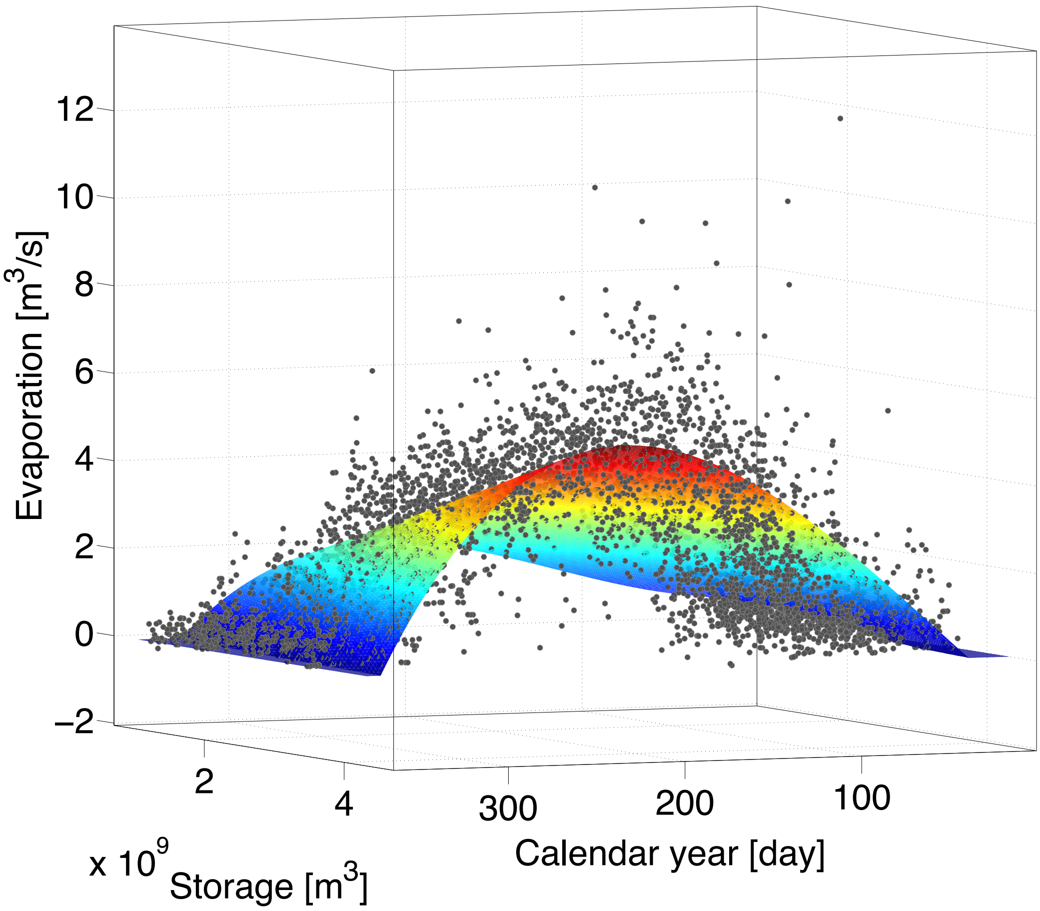

Figure 1. Observed evaporation (grey dots) and modeled evaporation (surface) as function of reservoir storage and day of the year.

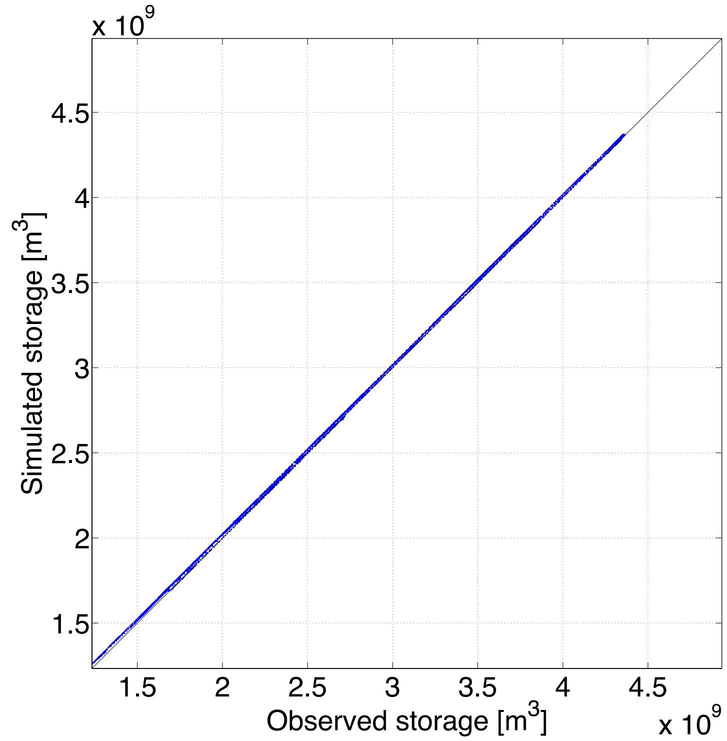

Figure 2. Scatter plot of observed and simulated reservoir storage through the mass balance model.